

Common Data Acquisition Systems (DAS) Software Development for Rocket Propulsion Test (RPT) Test Facilities – A General Overview

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ABSTRACT

The advent of the commercial space launch industry and NASA's more recent resumption of operation of Stennis Space Center's large test facilities after thirty years of contractor control resulted in a need for a non-proprietary data acquisition system (DAS) software to support government and commercial testing. The software is designed for modularity and adaptability to minimize the software development effort for current and future data systems. An additional benefit of the software's architecture is its ability to easily migrate to other testing facilities thus providing future commonality across Stennis. Adapting the software to other Rocket Propulsion Test (RPT) Centers such as MSFC, White Sands, and Plumbrook Station would provide additional commonality and help reduce testing costs for NASA. Ultimately, the software provides the government with unlimited rights and guarantees privacy of data to commercial entities.

The project engaged all RPT Centers and NASA's Independent Verification & Validation facility to enhance product quality. The design consists of a translation layer which provides the transparency of the software application layers to underlying hardware regardless of test facility location and a flexible and easily accessible database. This presentation addresses system technical design, issues encountered, and the status of Stennis' development and deployment.

KEY WORDS: data acquisition system, translation layer, calibration, data processing, hardware independent, recording, logging, evaluation, rocket propulsion testing

INTRODUCTION

As noted in the abstract, the transition of Stennis Space Center's (SSC's) large Test Complexes from contractor operated facilities to NASA operated facilities along with the commercial space launch initiative necessitate propulsion test facilities become more cost effective for performing test as well as being able to produce reliable data such that commercial propulsion test customers need not be concerned with the accuracy or integrity of their data. Historically, the A and B-Complex Test Facilities at SSC have been operated by a commercial entity which employed a proprietary software suite to operate the Data Acquisition Systems (DAS) at these facilities. In 2011, NASA assumed operation of these facilities instead of the commercial entity, yet had no government owned software to operate the DAS at these facilities. Therefore, NASA set out to develop a suite of software to operate these systems which would alleviate the concerns of potential commercial customers in addition to reaping the benefits of owning such a software set. The Rocket Propulsion Test (RPT) Program Office agreed to fund the effort with the understanding the software would be available for use with minimal modifications to all RPT centers. These centers are Stennis Space Center (SSC), Marshall Space Flight Center (MSFC), White Sands Test Facility (WSTF), and Plumbrook Station. The ability to be used at multiple centers which utilize differing DAS hardware with different capabilities drives a requirement for the software to be designed in a modular fashion to enhance portability. This paper describes the process for developing and implementing such a system along with the status of its implementation.

REQUIREMENTS DEVELOPMENT

The first step in this process was to gather and document a set of requirements for the software. Representatives from all RPT centers participated in the requirements gathering effort. This effort included visits to three of the four RPT centers (SSC, WSTF and Plumbrook Station) which took place during the fall of 2010. The resulting requirements set captured much of the functionality of the existing proprietary software set as well as operational and capability enhancements intended to improve the efficiency of operation of the software. In addition, the requirements set includes the ability to operate and control the DAS hardware for all four of the RPT centers, which is yet to be implemented.

INITIAL SYSTEM DEVELOPMENT AND IMPLEMENTATION

The need for such a system was more prevalent at SSC's A and B-Complex Test Facilities. Therefore, the project decided to implement the system at SSC's A2 Test Facility during testing of the J-2X rocket engine. Due to the necessity to quickly implement a functional system, the decision was made to develop the system with limited capabilities, based upon a sub-set of the software requirements to run in parallel with the proprietary software set on a secondary DAS at this facility. At this time, the project was named NASA DAS, or NDAS. The initial limited capability set was called Phase I of the project and the subsequent phase to implement the

remainder of the requirements was called Phase II. The team chosen to implement this system is based at SSC and includes NASA civil servants and on-site contractors.

SYSTEM ARCHITECTURE AND DESIGN

The system design needed to incorporate the necessary functions to operate a rocket propulsion test facility DAS and be flexible enough to be as independent of the DAS hardware as possible. Therefore, the design implements the Translation Layer, or NXLT, which translates the commands and data received from the DAS hardware components to the remainder of the system modules. This architecture is depicted in Figure 1 (SSC SATURN Conference, 7) below.

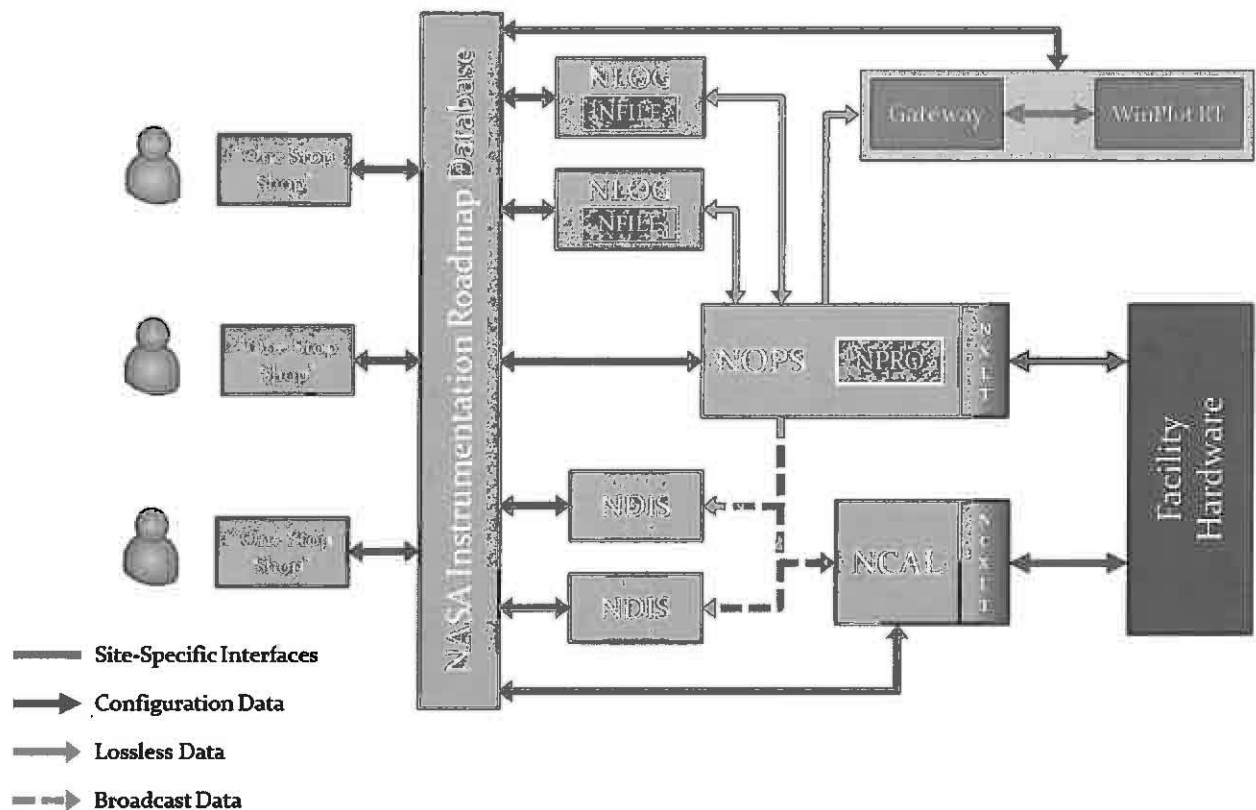


Figure 1 : NDAS Software Architecture Overview

The remainder of the functions required to be implemented by the NDAS software suite were modularized into the following functions, or Computer Software Configuration Items (CSCIs); DAS Operations (NOPS), Translation Layer (NXLT), Calibration (NCAL), Display (NDIS), Engineering Unit Processing (NPRO), Data Logging (NLOG), Data File (NFILE), Instrumentation Roadmap Database (NIRD), and Distributed Data Management System (NDMS). The functions and purposes of each of these CSCIs are described below.

NOPS DAS Operations

NOPS (for DAS Operations) is the CSCI which manages the translation layer (NXLT) connection to the DAS hardware (SSC SATURN Conference, 8). It also manages the data stream connections to the NDAS distributed software CSCIs such as NLOG, NCAL, and NDIS. It provides the framework for the NPRO module to perform Engineering Unit conversion on all

data at run-time. NOPS also manages and reports application level errors to the NLOG Application Programming Interface (API). A detailed view of the NOPS architecture is shown in Figure 2 (SSC SATURN Conference, 11) below.

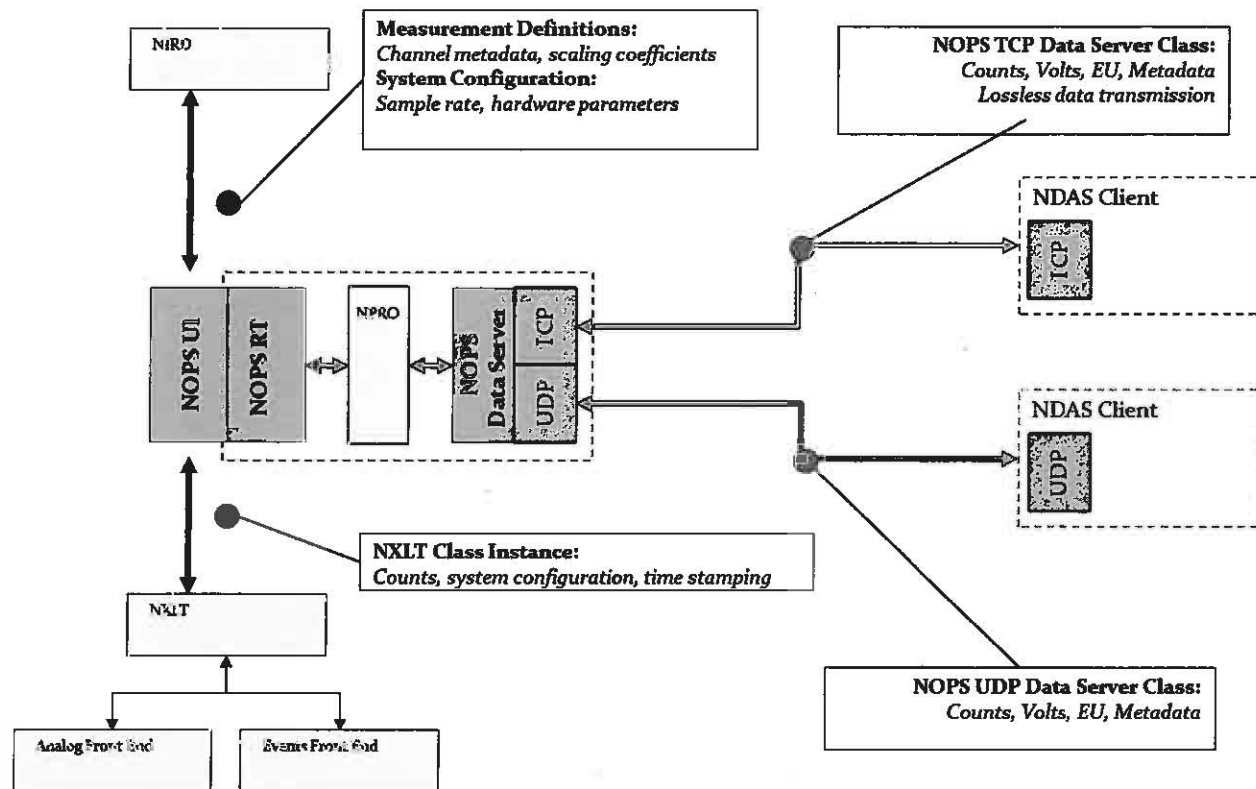


Figure 2 : NOPS Architecture

NXLT and NCXLT Translation Layer and Calibration Translation Layer

The Translation Layer is the layer which (SSC SATURN Conference, 15) provides an abstraction layer between NOPS and site specific acquisition hardware by masking the differences in hardware from the application software. This CSCI implements capability to support acquisition of data from multiple sources simultaneously. NXLT is initialized by NOPS using information stored in the NIRD database. The DAS hardware is configured during system initialization and stored in the NIRD.

NCXLT provides an abstraction layer between NCAL and site specific calibration sources and signal conditioners (SSC SATURN Conference, 15) by masking the differences in hardware from the application software. NCXLT is initialized by NCAL using information stored in the NIRD database. Calibration and signal conditioning hardware are configured during system initialization and stored in the NIRD.

NCAL Calibration

NCAL performs calibration, linearity/hysteresis, and Measurement System Analysis (MSA) (SSC SATURN Conference, 21). NCAL implements a modular, object oriented approach to calibration based on fundamental calibration "types". Calibrations are performed based on calibration instructions. The architecture allows for flexibility in defining a calibration process which may differ among centers or test programs. NCAL interfaces with hardware through the

NCXLT translation layer. All access to the DAS hardware is achieved through the high level NCXLT interface.

NCAL acquires data through the NOPS data stream, reads the NOPS network stream server, records and analyzes calibration result data, is self-contained with no reliance on separate downstream loggers/processors, interfaces directly with the database through the NIRD API, and retrieves and commits calibration routines and results with full audit control.

A detailed view of the NOPS architecture is shown in Figure 3 (SSC SATURN Conference, 22) below.

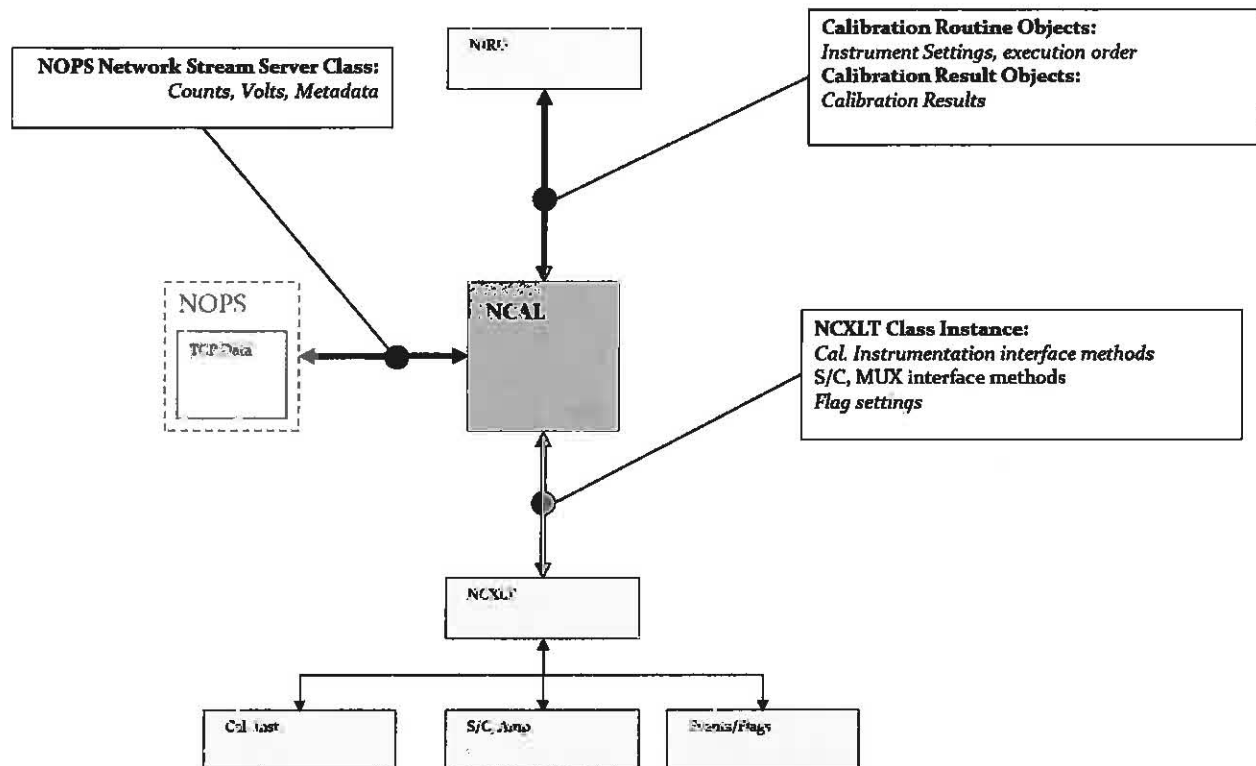


Figure 3 : NCAL Architecture

NDIS Display

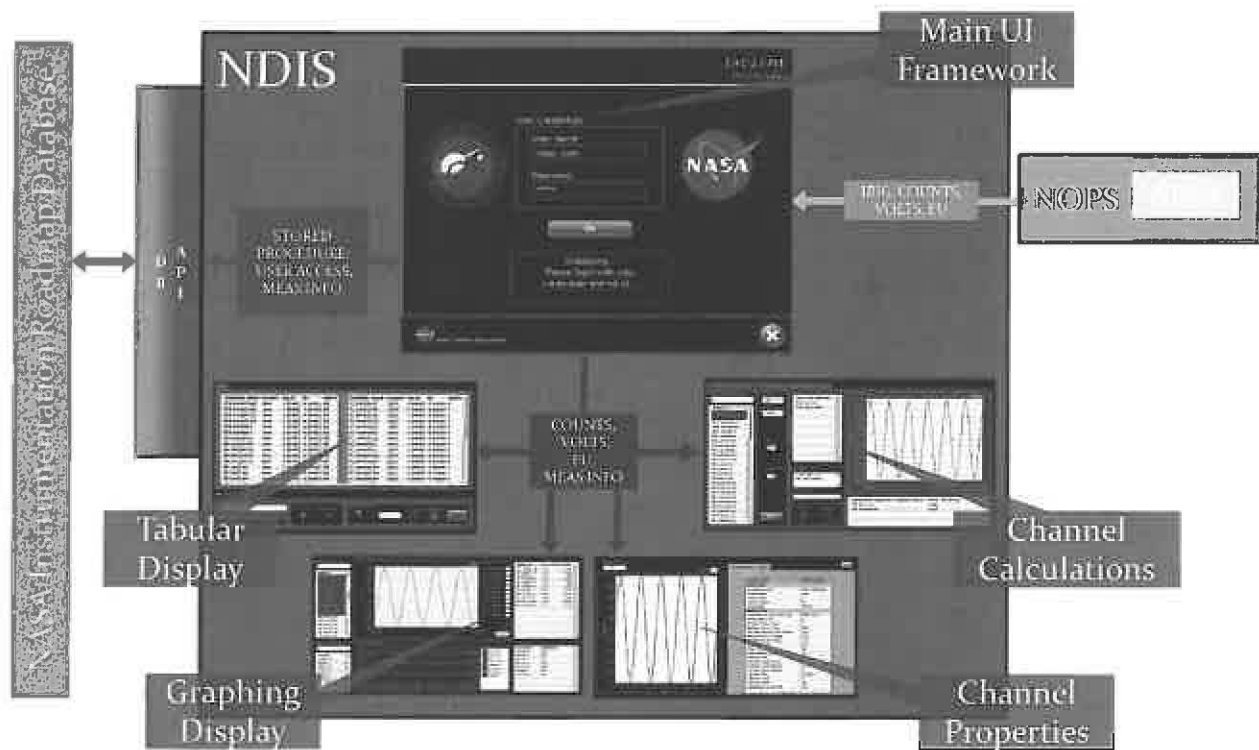


Figure 4 : NDIS Front Panel Example

Figure 4 (SSC SATURN Conference, 29) above depicts an example Front Panel Display from the NDIS CSCI. Figure 5 (SSC SATURN Conference, 30) below depicts the NDIS User Interface Framework.

UI Framework – Object Oriented (OO) State Machine

- * Follows recommended NI software design patterns
 - Queued event, OO state machine, consumer/producer
 - Aka ‘Chain of Command Pattern’
- * Uses **Dynamic Dispatching** to determine (at run-time) which version of the execute method runs
- * Execute method acts as a “OO state machine”
- * Architecture allows for continuous operation portions of the procedure.

Execute () – [“State Machine States”]

- Plugin Control Manager
- UI Control Manager
- DAQ Stream Handler
- Queue Handler
- Error Handler
- DB Handler
- Load Panel
- Slide Panel
- Login
- Logout
- Init
- Exit

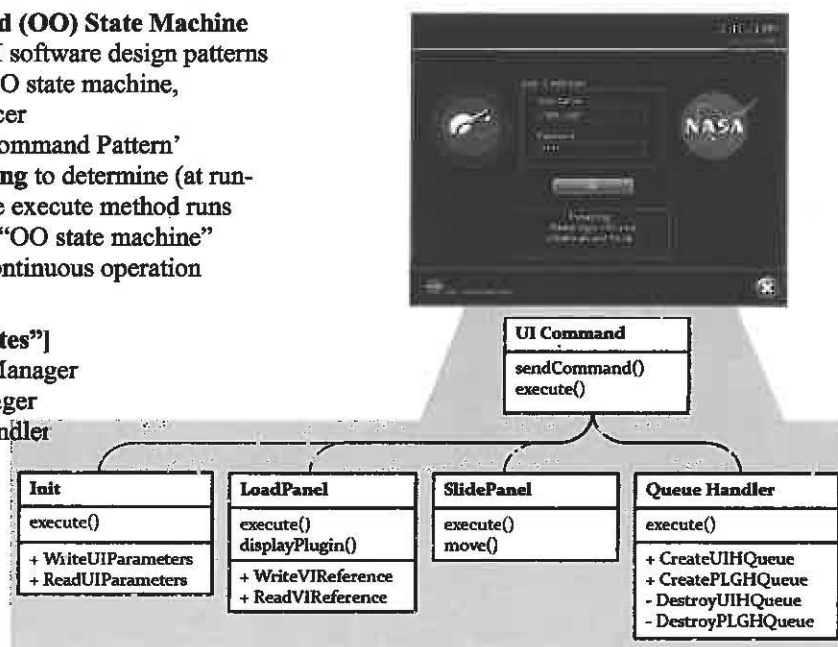


Figure 5 : NDIS User Interface Framework

Figure 6 (SSC SATURN Conference, 31) below depicts the NDIS User Interface Framework.

UI Framework – Plugins

- ❑ UI Framework follows NI factory design pattern for plugins (GUIs)
- ❑ Tabular, Graphing, Channel Props and Calcs GUIs – all plugins
- ❑ Plugin Handler & Error Handler
 - ❑ **Allows for 3rd party GUIs to be added without crashing NDAS System**
- ❑ User credentials – plugins available:
 - ❑ Tab, Graph, Props, Calc
- ❑ Admin credentials – plugins available:
 - ❑ Tab, Graph, Props, Calc, NLOG, NCAL, NOPS, 1SS

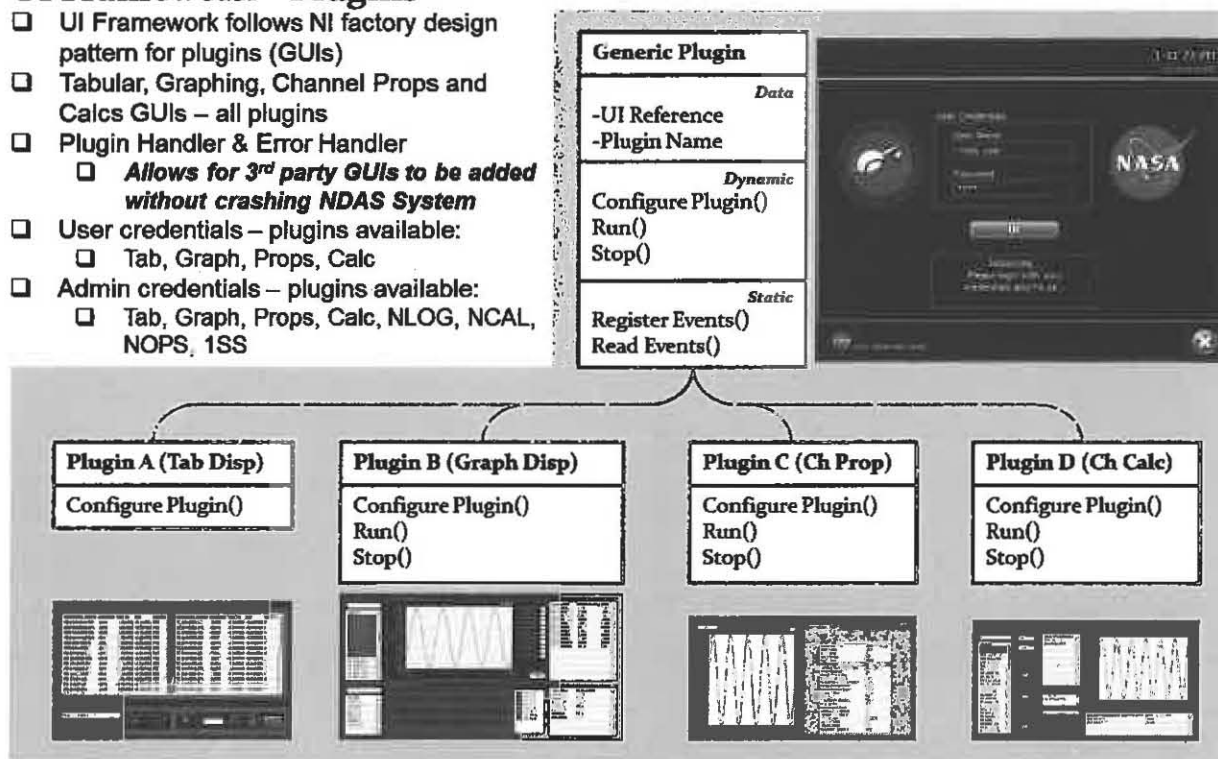


Figure 6 : NDIS User Interface Framework - Plug In Architecture

NPRO Engineering Unit Processing

The NPRO function provides data processing which converts the raw data into useable, Engineering Unit (EU) data. NPRO (SSC SATURN Conference, 17) can function as either an API called by NOPS or a stand-alone application which supports the production of Engineering Unit converted data for real-time display and storage. All data required to support EU conversions is housed in the NIRD.

NPRO provides output of data to support the NFILE module. This data becomes the official processed data reviewed and released to customers. In addition, this data is provided in real-time to NDIS to support displays during test activities.

NPRO's architecture provides the flexibility to enable expansion to meet customer specific requirements.

NPRO utilizes a class structure to organize the different engineering unit processes.

NPRO provides Engineering Unit data including but not limited to first order calculation, multi-order, discrete bits, pulse data, Resistive Temperature Devices (RTDs), thermocouples, density, mass flow, and special calculations. This module will be capable of handling scripts to automate processing in future implementations.

NPRO incorporates all existing calculations with the ability to easily insert additional calculation types using Object-Oriented Design and LabVIEW equations parsing via formula nodes.

Engineering Unit data is generated using National Institute of Standards and Technology (NIST) traceable techniques such as the International Temperature Scale-90 (ITS90) used for RTDs or NIST lookup tables.

A detailed view of the NPRO Algorithm Class Hierarchy is shown in [Figure 7](#) (SSC SATURN Conference, 18) below, while [Figure 8](#) (SSC SATURN Conference, 18) shows the implementation of the NPRO CSCI.

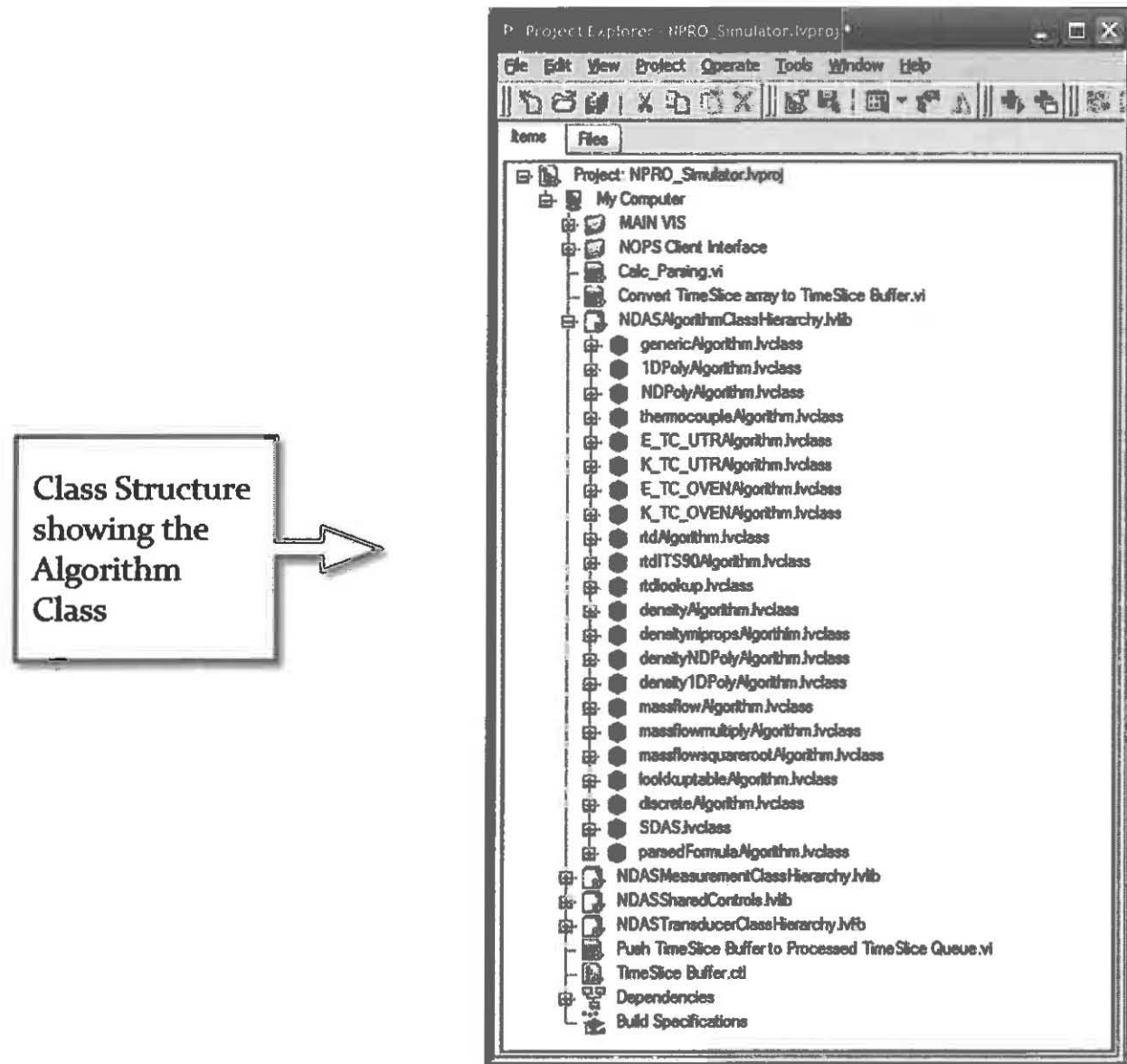


Figure 7 : NPRO - Algorithm Class Hierarchy

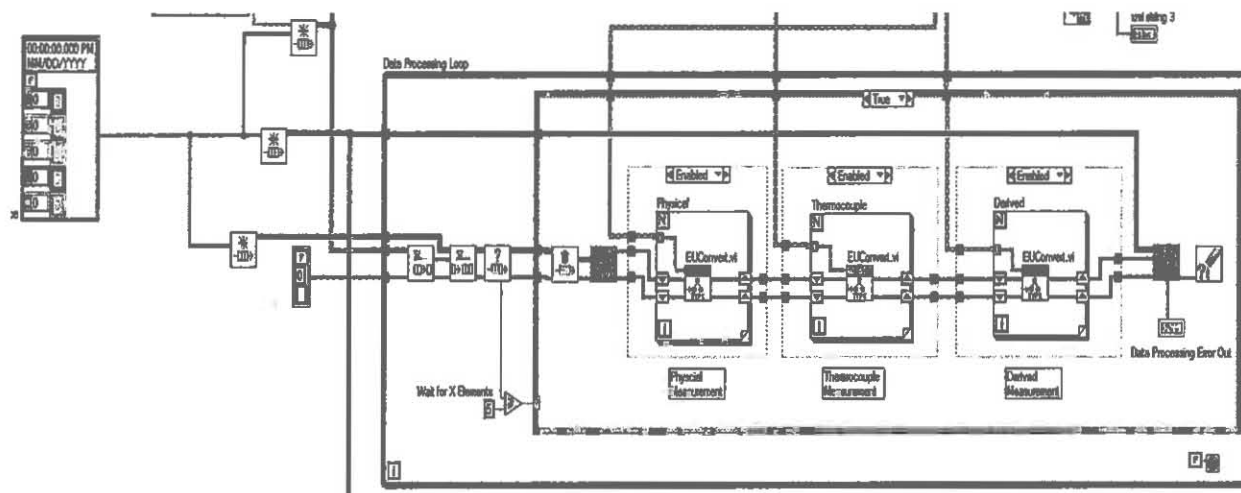


Figure 8 : NPRO Implementation

NLOG and NFILE Data Logging and Data Filing

NLOG/NFILE are CSCIs which are opened by a user or other NDAS modules. This CSCI logs the NOPS stream data into the selected format from the options of a Technical Data Management Streaming (TDMS) data file or a TDMS FIFO buffer directory. The NLOG/NFILE CSCIs convert TDMS files to other file formats. Standard formats in NDAS include Matlab, WinPlot (a free NASA developed application for data viewing and plotting), and Comma Separate Values (CSV) files. These CSCIs are easily modifiable to provide customer specific file formats.

Figure 9 (SSC SATURN Conference, 43) shows the functionality of the NLOG/NFILE CSCIs.

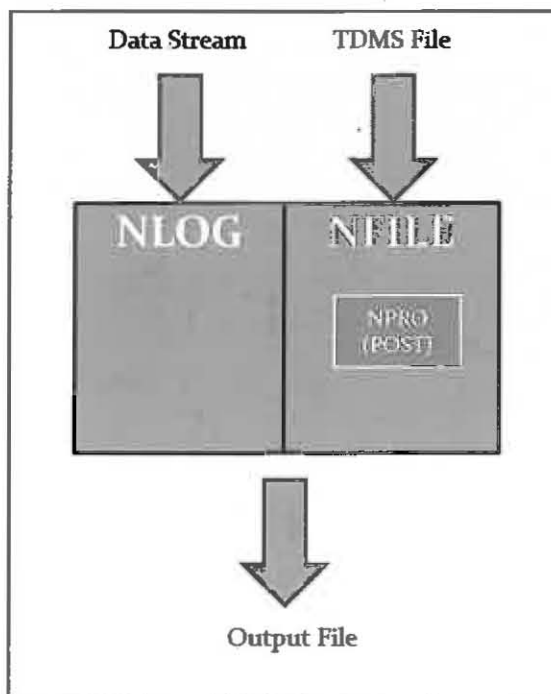


Figure 9 : NLOG/NFILE Functionality

NIRD Instrumentation Roadmap Database

NIRD is the CSCI which serves as the database function for the NDAS software suite. In order to properly configure the system with information required to operate the DAS, such as how many channels are needed for testing, which instrument is connected to which DAS signal conditioner and acquisition channel, etc. the information must be entered into NIRD.

The NIRD component structure is depicted in Figure 10 (SSC SATURN Conference, 33).

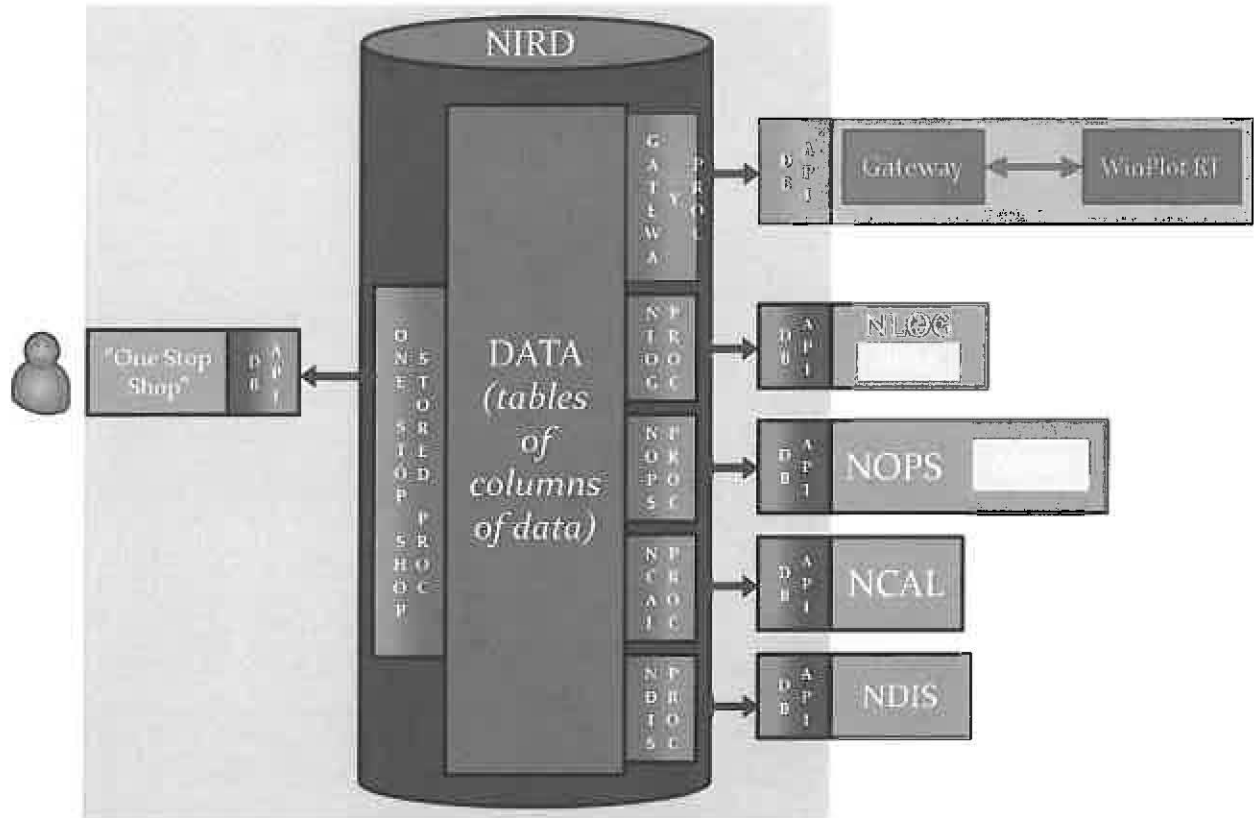


Figure 10 : NIRD Component Structure

The NIRD also implements a One-Stop-Shop functionality in which most of the information required to configure the facility DAS can be stored and accessed by a user. [Figure 11](#) (SSC SATURN Conference, 34) depicts the functions and capabilities of the One-Stop-Shop.

- GUI - main user entry point into NIRD
- Display system HW components
- Setup measurements
- Setup calibration routines



Stored Procedures (SSC SATURN Conference, 36)

Some of the benefits of using stored procedures include allowing the work of retrieving data on the server side, not on the application/client side of the database, making it easier to maintain the database and all NDAS database maintenance/upgrades which can be assigned to a database administrator. Therefore, the Centers do not have to acquire additional personnel to maintain the database. Non-LabVIEW NDAS code is maintained in one area. Database personnel do not need training in LabVIEW. Also, procedures/routines can be stored with backups or archives.

Database models:

- NASA Instrumentation
-
- Roadmap Database

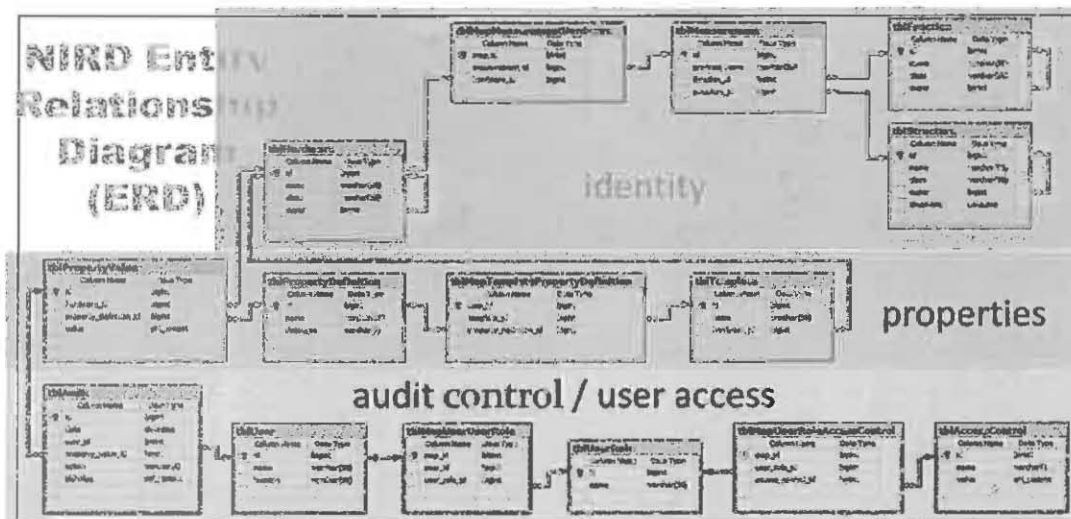


Figure 12 : NIRD Structure

The ability to easily adapt the system during implementation is a key concept of NDAS. Figure 13 (SSC SATURN Conference, 38) depicts how NIRD's flexible hierarchical structure allows for deployment to any test configuration.

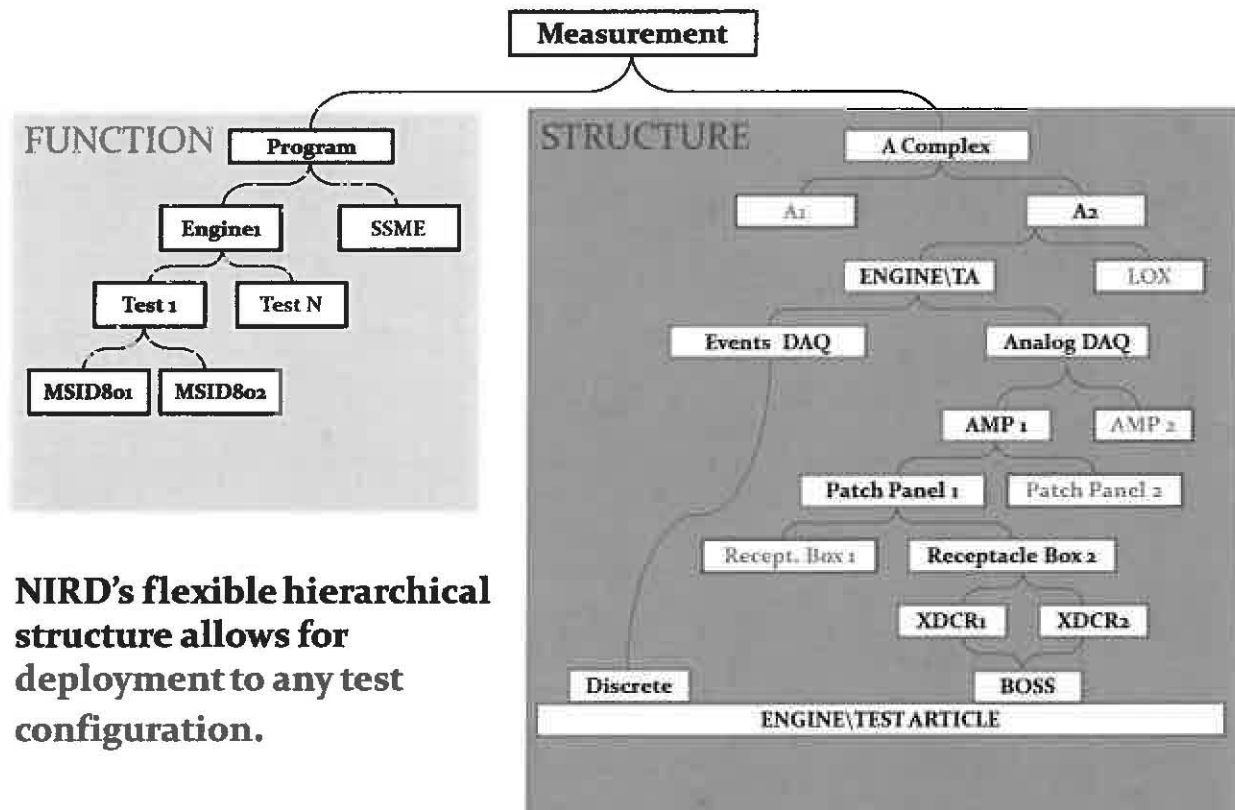


Figure 13 : NIRD System Component Storage

NDMS Distributed Data Management System

NDAS software is able to support remote (off-site) data transmission using the Integrated Advisory System (IAS) by use of a protocol which is compatible with a real-time version of NASA's data plotting application, WinPlot.

NDMS reads data from NIRD and NOPS, performs engineering unit conversion on the data being transmitted, and then transmits the data through the User Datagram Protocol (UDP) to off-site locations which can be located at any customer facility. Data transmission supports both point-to-point, which requires a specific target Internet Protocol (IP) address, and multi-cast, which can be sent to any IP address transmission methods.

TESTING PLAN

The plan for testing of the NDAS software is to run the software on the secondary DAS at the A2 Test facility during active J-2X rocket engine tests. Then, the data is compared to the data acquired on the primary system using the proprietary software for discrepancies. Several discrepancies between the primary and secondary systems were identified prior to use of NDAS on the secondary system. These channels were not used in the comparison. The project determined a minimum of five (5) tests were required to obtain sufficient data samples for the comparison to be considered valid. To date, these five tests have been completed and the

analysis comparing the data acquired from the primary (SDAS) and secondary (NDAS) systems is on-going.

TRADE STUDIES

During the development of the requirements set, a trade study was initiated to determine the most appropriate development environments to use for the software development effort. One of the options considered for the programming language was the Experimental Physics and Industrial Control System (EPICS) which is an open source type of environment popular in the physics community. Another option which was considered and ultimately selected due to the familiarity with the coding was a graphical data flow environment known as the Laboratory Virtual Engineering Workbench (LabVIEW).

Another trade study was performed during the development cycle was an evaluation of an open-source Structured Query Language (SQL) server instead of a Commercial-Off-the-Shelf (COTS) SQL server application. NASA does allow use of open-source software once such use is reviewed and approved by legal counsel. The use of open-source applications is preferred to reduce the long term costs. The initial deployment of the system at SSC uses a COTS SQL server; however, subsequent implementations will use the open-source implementation pending legal review and approval of such use.

DEVELOPMENT AND DEPLOYMENT STATUS

The NDAS Phase I and II development has been completed and Beta Version 1.0 has been released for use on the secondary data system at the A2 Test Facility. The NDAS software has been running on the secondary low speed DAS at A2 since late November of 2011. The software development team has been focused on assuring the data acquired from both the primary and secondary DAS are in agreement.

The data sets collected from the J2X Tests are currently being reviewed by an independent SSC group of engineers.

NASA's IV&V facility has peer-reviewed the software and released a final report regarding the software's completion. After items identified in the IV&V final report have been resolved, the NDAS Software Revision 0 will be released in SSC's software configuration management system. The anticipated release date is November 2012.

Funding will be provided to migrate the NDAS software to other test facilities at SSC. Currently, the team is assessing requirements to make these migrations.

REFERENCES [List in alphabetical order according to primary author last name]

SSC, SATURN Conference Presentation, May, 2012.

BIOGRAPHIES

Phillip W. Hebert, Sr. is the Lead of the Software Engineering Group within the Engineering & Test Directorate (E&TD) at NASA's John C. Stennis Space Center (SSC) in Mississippi. Mr. Hebert has over 20 years of experience in the aerospace industry at three NASA facilities as an electrical and computer engineer. His experience at NASA facilities range from a software and electrical engineer at both Kennedy Space Center (KSC) and SSC, with a one-year detail at NASA's Marshall Space Flight Center (MSFC). For his efforts, he has earned an Exceptional

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